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Drying Rates, Infrared Drying, and Binder Migration

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DRYING RATES, INFRARED DRYING, AND BINDER MIGRATION

by

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DRYING RATES, INFRARED

DRYING, AND BINDER MIGRATION

Proper distribution of adhesive in pigmented coatings is necessary to obtain good printability. This [illegible] undertaken to study the effect of varying drying rates on adhesive distribution. Using a standard substrate, coating was dried under four separate drying rates on a pilot coater equiped with an air knife coater and three sections of hot air driers. After grinding to various depths, a spectrophotometric method was used to analyze migration behavior. The fastest rate, utilizing an infrared heater temporarily placed directly after the air knife, showed extremely uniform adhesive distribution. This was due in part to the reflective foil placed opposite the infrared heater, allowing evaporation in both directions. Successively slower rates were obtained by moving hot air zones away from the application area. The hot air driers were temperature controlled to 350° F in the hot zone and 200° F in the other two sections. Results showed surface migration directly proportional to the distance to the hot zone, contrary to the theories based on previous studies. The reason postulated for this phenomena was "thermal migration" during the intermediate zones. Spectrophotometric analysis was found to be an effective and feasible method to study adhesive migration.

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INTRODUCTION

A coating mix consists of one or more pigments, one or more binders, water or other solvents, and additives. Upon coating application, the substrate does not remain passive since it has the tendency to absorb the liquid coating, predominately, binder and solvent, before drying takes place. This is a technically important effect since the composition of the dry coating is no longer the same as the original mix (2). When the same system is exposed to the high temperatures of drying, the coating mix is again altered by redistribution of the water and dissolved substances.

Adhesive redistribution or more commonly, binder migration, is the selective movement of adhesive through a pigmented coating. This means that the adhesive can migrate into the substrate or out toward the coating surface. In this paper, migration will be assured to mean migration into the sheet unless otherwise specified. Migration into the substrate results in inadequate binder levels to sufficiently bond the coating to the substrate, which can present problems in the printing operation such as dusting, picking and changes in ink receptivity.(4). Migration away

from the sheet manifests itself as railroad tracking, mottling, poor gluing and surface gloss, differences in ink receptivity, and other coating and printing properties (4). Thus, it is necessary to control migration to obtain the desired effects. Since this is not now absolutely possible, the cause for research and experimentation is apparent.

HISTORICAL BACKGROUND

There is a commonly accepted theory that binder migration follows the same path as water leaving the coating. Many researchers have postulated theories about and reasons for binder migration and have shown that the binder does migrate and apparently does follow the same pattern as the water leaving the coating (1). There are many variables affecting this pattern (see table 1).

First of all, the substrate's ability to soak in water has an obvious effect. It has been shown many times that a more absorptive base sheet will increase binder migration into the sheet (1-3, 5). Normally, if the substrate has been sized, the absorbancy will decrease, thus, decreasing the amount of binder migration (6). This is accomplished by closing in some of the porous areas and by rejecting water as some sizes are designed for. The type of binder plays an important role also since all binder are not attracted to the substrate alike. For example, it has been found that soluable binders have a greater tendency to migrate than latex particles and where the latter are concerned, those of smaller particle size migrate more easily (1, 3). It is also well known that different coating clays have

different water retention properties. For instance, a well hydrated china clay produces higher values than a less hydrated pigment such as calcium carborate and therefore, will hold the liquid suspended in the pigment better (2). Clark et. al. (6) have shown that migration is directly porportional to pressure at the applicator roll and the blade. They also proved the supposition that the length of time from application to the first drying stages is directly proportional to inward migration (6, 3). In their studies they classified migration into two distinct stages--pressure and capillary migration.

Pressure migration, as the name implys, is migration of the fluid upon pressure exerted on the fluid system. An example would be migration occuring at the moment of pressure exertion by the applicator roll. Another would be pressure caused by gravity forces on the fluid system. Capillary migration is migration associated with fluid flowing through the pores and channels of the base sheet. At first, the fluid flows from wet to dry--towards the substrate. Then upon rapid drying, evaporation causes migration to the surface. Since the purpose here is to study the effect of drying rates on migration it is capillary migration which is the primary concern. However, neither type of migration is negligible compared to each other. Frequently, in fact, both migrations appear to be of the same order of magnitude.

The viscosity of the liquid (pigment-solvent-binder) system is obviously a major factor in binder migration as evidenced by several studies (1, 2, 6). Several factors influencing viscosity are percent solids in the color, percent binder, type of binder, type of pigment, and additives, such as alginates. As mentioned before, all pigments and binders have their own properties including viscosity. Eklund and Palsanen (3) state that the type of binder does not influence the direction of migration but rather the magnitude. The amount of binder in the color was also shown to be proportional to the amount of migration (3, 6). Any pigment with a higher viscosity would seem to give less migration, which has indeed been witnessed by several people (1, 3).

Addition of alginates is also known to increase the vicosity and thus decrease migration. This was especially apparent in a study done by Clark et. al. (6). They also demonstrated that NaOH as a pH thickening agent was effective but to a lesser degree. On the whole, additives seem to have much more promise than other parameters.

The percent solids content affects the migration by eliminating as much water as possible, which will decrease binder migration since it has already been assumed they travel together. Almost all references refer to high solids content as a sure way of combatting migration (1-4, 5).

Last is the effect of drying rates on binder migration. Hieser and Cullen (1) found that the principle direction

of migration, whether mainly toward the substrate or mainly toward the surface, was dependant on drying rate. Eklund and Pasenen (3) concluded that when the intensity of drying was decreased migration increased especially for highly absorbant papers. They also stated that cylinder drying in the initial stage of drying induces binder migration toward the outer surface of the paper. G. R. Schut (7) reported that if a certain drying rate was exceeded, migration was drastically affected and of particular importance was the drying intensity at the beginning.

Gas-infrared drying combined with hot air of low velocity was found to be the optimum solution by Thomin et. al. (5). This is quite important to this study since a very similar sequence will be used.

JUSTIFICATION

Upon inspection, it is plain to see that many of the variables mentioned can not be changed significantly without affecting the requirements specified by customer order (denoted by O on table 1). Other variables seem nearly impossible to change except by reconstruction of the coating machine (denoted by M on table 1). These vast limitations leave us with solids content, and drying rates to work with. From the rheological standpoint and coat weight control requirements on high speed coaters, the solids approach appears quite limited. For these reasons I chose to

determine the effective drying rate of a specific paper-pigment-binder system. These results obtained will be valid only for the specific paper-pigment-binder system employed during the testing (6,7).

All experimenters until now have lacked a feasible method of accurately evaluating the effectiveness of changing any parameter. What was needed most was a method of quantitatively evaluating the nature of migration by measuring the amount of binder in each of several selected layers of the pigment-adhesive-substrate system. Such a system must be able to measure the concentration of binder in relation to concentration of clay. The method we intend to use is a Multiple Internal Reflectance (MIR) spectrophotometer. Sheets will be measured for binder concentration by means of a mechanically drawn graph of absorbance verses wave length. By isolating the wave length of our specific binder and of clay we can measure relative concentration by the amount of absorbance indicated on the graph. Then, after grinding the surface down several thousandths of an inch and running a sample through the MIR again, we can find the concentration of binder at any level inside the sheet. In this manner we expect to be able to accurately measure the extent of binder migration. More details on the actual method will be included in the experimental section.

MIGRATION PARAMETERS

TABLE I — STATUS

I. Substrate affinity for binder

- A. Swellability, absorbancy, porosity.....O
- B. Sizing-type and amount.....O
- C. Type binder or fiber.....O

II. Clay affinity for binder

- A. Type clay--water retention value.....O
- B. Type binder--affinity for pigment.....O

III. Machine variables

- A. Blade pressure.....O
- B. Applicator roll pressure.....M
- C. Time log: application to first dryer.....M
- D. Drying rate.....-

IV. Viscosity of fluid system

- A. Percent of solids.....-
- B. Binder content.....O
- C. Additives--type and amount.....O
- D. Particle size.....O
- E. Type binder or pigment.....O

In the experiment all parameters will be independent and fixed variables except drying rate which will be the dependent variable.

EXPERIMENTAL

Pre-experimentation consists of making up the coating color, selecting a base stock, setting up the infrared dryer, calculations of materials needed, and devising a drying scheme. The color was mixed one day in advance with the binder being mixed on the day of the trial. A base stock which had little or no sizing or additives and therefore, considerable absorbance, was selected out of the inventory in the machine room. The infrared dryer was installed several days prior to the trial. It was placed directly between the first air hood and the air knife of the application system. Calculations of materials needed, and the drying scheme used are shown in the appendix as are further details on the base stock and coating make-up.

The trial, run in December of 1974, lasted only one day and went fairly smooth. We ran four different coatings on the main base stock and one coating on an internally sized sheet. During lab work the fifth coating run was discarded because the coating did not cover the surface well due to the sheet's resistance to absorbance; in fact, the coating solution merely beaded up on the surface. More specifics on the machine are found in the appendix as well as a simple schematic.

Markers were inserted during the run to keep track of the samples of different drying zones. Samples were taken by slabbing down the windup reel and cutting the coated paper into two foot squares. Later samples were cut into sizes corresponding to the test being run. We ran several optical tests and two printing tests, namely the I.G.T. pick test andthe K. & N. absorption test. Following is an analysis of these six test results.

As shown in Table II, the optical tests did not offer much in the form of trends in the data. We ran Ro, R_{92}, Roo, and opacity on all four coats. Nothing on these tests indicated that faster drying rates affected the optical properties. The only trends that can be seen are due to different coating make-ups. It appears that the alginate additives did make a slight difference and also that the styrene butadiene used in coats three and four had a slight effect. Coats two and four (alg.) are consistently slightly higher in brightness than coats one and three (no alg.). Coats three and four (SBD) also ran a little higher than their coat one and two (latex) counterparts. This indicates that not only did the alginate affect the optical properties but, apparently, styrene butadiene has it's own particular optical characteristic, which subsequently affects the optical properties of the coating. It's not known why the alginate would affect the optical properties except that by making the coating more viscous more stayed on top causing the change in the optical properties. Other wise,

the coat weight variation, upon inspection, may indicate the reason for the variation in brightness. As can be seen (table II) the coat weight values shed some light on the subject. Apparently, our optical results are based on the amount of coating applied onto the sheet, which is logical. We notice that coats two and four have the highest weight, that coat three is higher than coat one and that our data ran a similar pattern. Thus, it can be that neither drying rate nor alginate had any real effect on the optical properties.

The effect of varying coat weight can also be seen in the K. & N. where we measure, in effect, the amount of ink that will be absorbed into the coating. With more coating on the sheet, naturally more can be absorbed; the amount of adhesive in the coating was held constant. However, one more trend can be noticed. In coat two the K. & N. results went down from the IR to zone three, which indicates similar migration characteristics to that shown in MIR data. That is, birder is distributed very uniformly in the IR sections and gradually concentrated more toward the surface as the heating zone was moved down to zone three. Since our coating--substrate interface is about 8-10/10,000 of an inch down from the surface, the congomeration of binder at the surface would probably not directly affect the K. & N. test results. However, as more binder concentrated itself at the surface less was concentrated at the interface causing a decrease

in K. & N. values. This type of result did not show up in any of the other coating trials which leads to the suspicion that they may be erroneous but nevertheless, a reason for the behavior is given.

In our quest to use an absorbant sheet, while being restricted to existing supplies in the pilot plant, we ran into a problem when it came to the I.G.T. pick test. Whenever we tried to run a test the sheet failed internally before picking occurred. However, one important point can be brought up. The sheets failed more easily when dried slowly, specifically in zones two and three. This indicates binder migration towards the substrate has occured and has strengthened the sheet internally in that we still found sheet failure but were able to use a faster speed on the I.G.T. pick tester before failure occured on sheets dried with the infrared heater and in zone one.

It should be mentioned here that more work should be done concerning the I.G.T. test because it would seem to be an applicable test to measure the effects of binder migration, especially into the substrate.

TABLE II

	IR	Z1	Z2	Z3	IR	Z1	Z2	Z3
	Brightness R_{00}				Opacity			
coat 1	70.1	71.0	70.6	70.5	91.3	91.1	91.5	91.4
coat 2	72.8	73.5	73.0	72.5	91.4	91.9	91.8	91.5
coat 3	72.8	73.0	72.0	72.3	91.6	91.5	91.6	91.2
coat 4	74.0	74.5	74.0	74.0	93.1	92.2	92.1	92.2
Blank	63.3				83.6			
	Ro				R_{92}			
coat 1	69.1	71.5	71.7	71.6	71.6	71.3	71.2	72.0
coat 2	70.0	72.5	71.0	72.0	73.5	74.0	74.2	73.8
coat 3	69.0	72.6	71.0	71.5	73.0	72.7	72.6	72.9
coat 4	70.5	72.4	71.0	71.7	73.5	73.8	73.0	73.2
Blank	63.1				66.8			
	K. & N.				Coat weights			% Solids
coat 1	.49	.50	.49	.48	16.775 ± .225			50
coat 2	.48	.45	.44	.42	18.725 ± .140			51.9
coat 3	.39	.41	.41	.41	18.59 ± .09			50.2
coat 4	.43	.38	.39	.43	20.05 ± .275			52.1
Blank	.52							

M.I.R. Analysis

It is commonly known that atoms and molecules absorb light at discreet wavelengths. If a spectrum of light is sent through a paper sample, certain wavelengths will be absorbed by substances in the sheet by nature of their particular chemical bonds (see figure 2). For example, one of the absorption spectra of Kaolin lies at 1000 cm-1. One of acrylic latex binder lies at 1725 cm-1. Thus by sending a wide spectrum of light through our coated samples we could expect absorption at wavelengths 1725-1 and 1000 cm-1 to occur. A device that can send a spectrum of light through a substance, measure and record the amount of absorbance and measure and record the wavelength at which the absorbance occurs is the Perkin Elmer Model 700 Spectrophometer with Wilks Scientific Corp. Model 50 Multiple Internal Reflectance attachment. The entire unit will be referred to as the MIR (see figure in appendix section).

PREPARATION

The MIR sends a spectrum of light through a sample sheet as shown in figure 4. Once through the sheet a series of mirrors sends the beam to the spectrophotometer measuring system. Another identical beam is sent to the

measuring system to reference the meter to zero absorbance. For our purposes, absorbance was recorded at all wavelengths in a spectrum between 3000 cm^{-1} and 800 cm^{-1}. The measurement was recorded by means of a mechanically drawn graph with absorbance in percent as the ordinate and wavelength in inverse centimeters as the absissa (see figure of spectrum in appendix).

Sheets were cut into sample sizes and supercalendered at 40 lbs./linear inch, 8 nips total. Then, small pieces, 5/8" x 1½", were cut to be used in the MIR. The absorption spectrums for Kaolin and acrylic latex binder were obtained from a report published by Jayme and Damaso (2). We ran only coatings one and two since the binder (styrene butidiene) used on coatings three and four had an absorption spectrum too close to the Kaolin spectrum to allow differentiation. So MIR migration analysis was possible only on coatings one and two using the acrylic latex binder.

The grinding technique left something to be desired. From the beginning we suffered a setback as the grinder in the physical sciences department had broken down so the grinding was done on a home grinder by Pete Bradshaw. Some error was encountered here as the thickness gauge was not measured in ten-thousandths of an inch. So guess work was necessary making for an error of perhaps one or two ten-thousandths of an inch for each grinding. Also, upon magnification it was plain to see that even as far down as ten ten-thousanths of an inch we still had not touched certain valleys of the surface of the substrate.

This means that at all levels with less than ten ten-thousanths of an inch ground off we were measuring some surface binder along with migrated binder. This is not conducive to reliable indicative data and I suggest that a superior grinding technique in subsequent trials would be advantageous.

TECHNIQUE

The Multiple Internal Reflectance migration analysis did, however, reveal some interesting facts about drying speed and infrared drying. Before results could be compiled a standard reproducible technique had to be developed. Several days were spent familiarizing ourselves with the spectrophometer and it's characteristics. After much experience it seems necessary to calibrate the MIR each time it is to be used. This involves two things. One, the mirrors must be placed in position so as to optimise beam reflectance. If the gain and sensitivity dials have not been altered they should not have to be moved appreciably. Lastly, it is strongly suggested that standard calibration samples be run through each day of use.

Once the sample had been graphed onto the spectrum graph paper a standard technique had to be developed for measuring the amount of binder with respect to clay. Referring to the spectrum following this page, a base line had to be drawn due to the MIR's tendancy to drift, making the top or 100% absorbance line inadequate. The line was drawn

by choosing several points on the curve that remained constant among all samples, namely, at 1800, 1300, and 800 cm^{-1}. The base line was drawn as shown by the dotted line exactly the same for each sample. The magnitude of acrylic latex band at 1700cm^{-1} was then the space between the base line and the bottom of the curve, shown by the arrow at 1700cm^{-1}. The clay band was taken to be the shoulder encountered at 1080cm^{-1} because the band at 1000cm^{-1} often times went off scale which prevented measurement. But the shoulder did correspond very well to the amount of clay present and since the same spot was carefully chosen each time this did yeild accurate and consistent results. As with the binder, the space between the shoulder and base line was the amount of absorbance taking place because of the clay. However these values obtained from the spectrum are not sufficient to give percentages of adhesive at the different levels. A mathematical relationship was used to obtain extinction coefficients from the transmittance values. From the spectrum the magnitudes of the absorbance by the latex and clay were given symbols as shown on the figure. I_o corresponds to the base line value, I_A corresponds to the bottom value of the acrylic band, and I_c to the shoulder of the clay band. Subtracting I_A and I_c from their respective I_o yeilded magnitude of absorbance. Taking logrithms and dividing yeilded extinction coefficients as shown below.

$$\frac{\ln (I_o - I_c)}{\ln (I_o - I_a)} = E$$

REMARKS

1 ≠ 3
1 crystal

ORIGIN

PURITY

PHASE

CONCENTRATION

THICKNESS

DATE 3/25/75

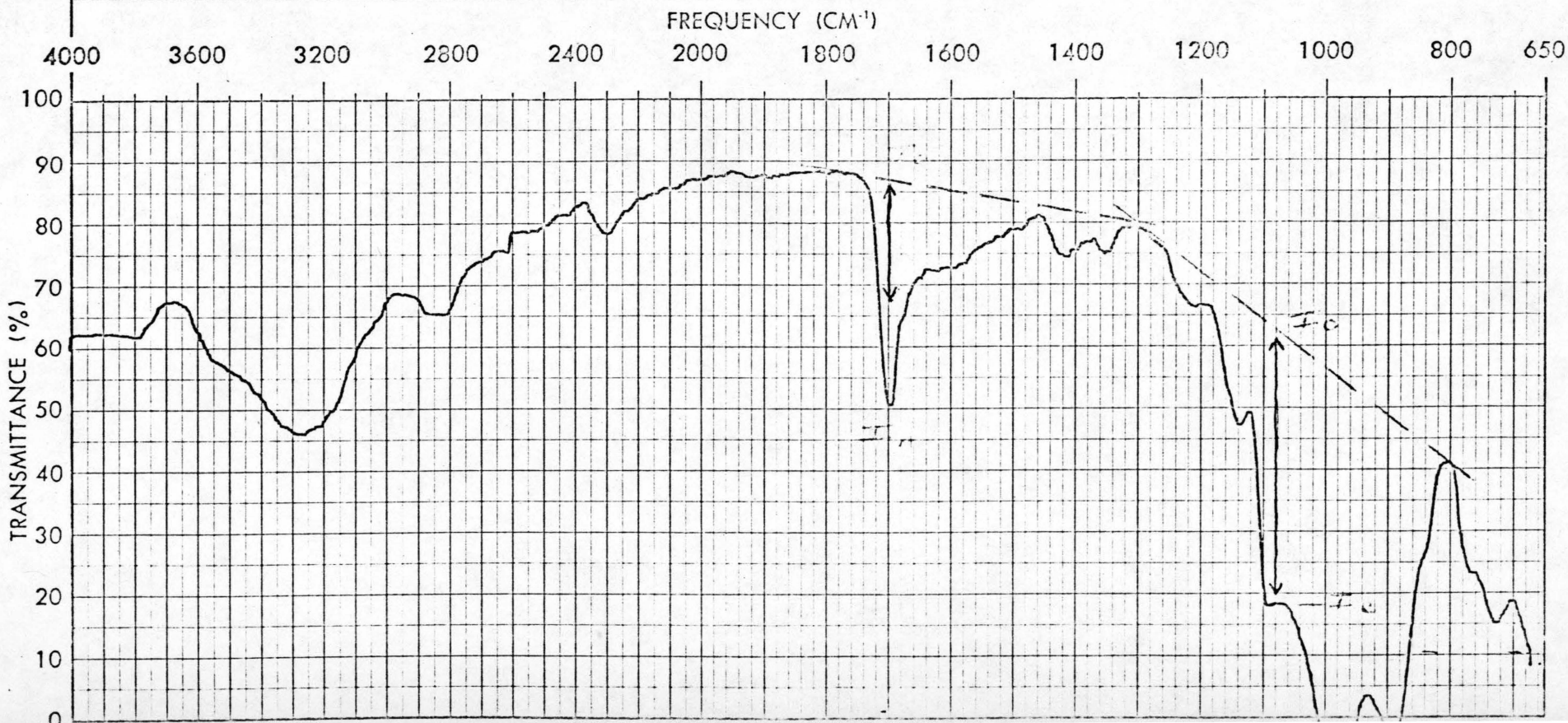
OPERATOR

PERKIN-ELMER
MODEL 700

SPECTRUM NO.

SAMPLE 1

SAMPLE 2



(19)

The extinction coefficient, , could then be used in conjunction with extinction coefficients calculated from calibration spectrums. Sheets were made with 0, 10, 20, 30 and 40% latex in the coating and processed to sample size by Fred Huang. By running these through the IRL, obtaining extinction coefficients, and graphing E versus percent latex we could find M, the slope which serves as a multiplication factor for all extinction coefficients found during the same day the calibration samples were run. This manipulation yeilds percent adhesive with respect to clay.

MECHANISM OF MIGRATION

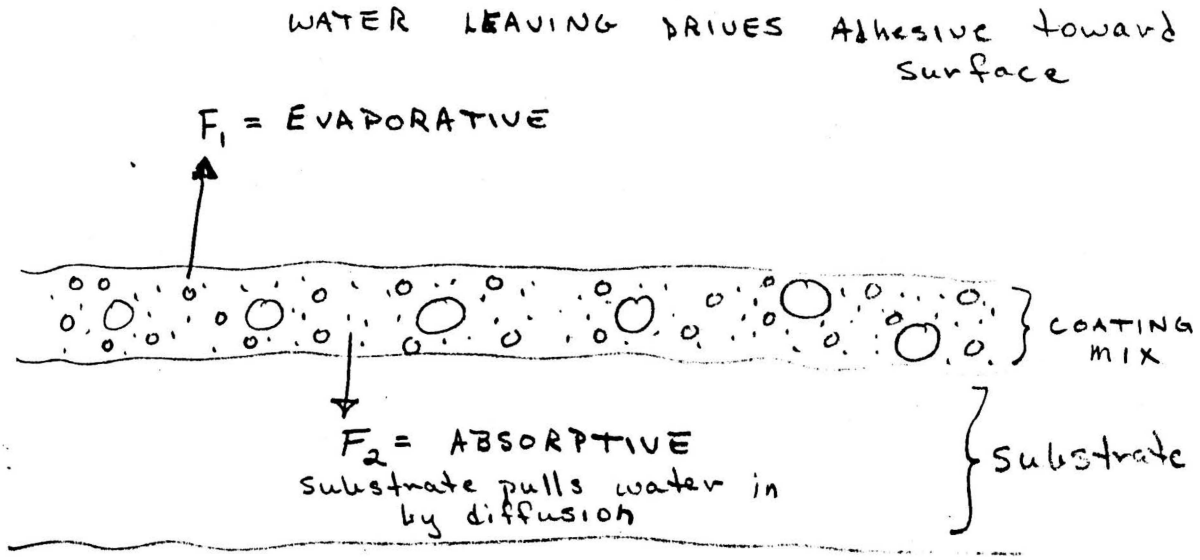
In the study of binder migration, a thorough understanding of the process has been gained. (Refer to figure below.) There is a 50% water solution applied on top of a 95% solid substance. Naturally, the latter tends to absorb the moisture out of the solution until an equilibrium is reached. However, long before an equilibrium is reached, the entire system is subjected to high temperatures causing evaporation. There are other forces on the moisture, e.g. gravity, but these are considered negligible because of the short time span involved and the magnitude of the absorptive and evaporative forces.

In this solution are three main substances--pigment, adhesive and water. The force exerted on the water is distributed on each one of the particles, making up the fluid.

When a force is exerted on these particles, unless resisted by another force, they will move in the direction of the force, colliding with other adhesive and pigment particles. The pigment particle size and density prevents the water particles from having much of an effect even though the reaction will, logically, be in the direction of the force on the water particles. The adhesive particles, on the other hand, are of small enough proportions to be effected greatly. It is well known, and specifically noted by Hieser and Cullen [1], that the adhesive particles do follow the same path as the water, whether it be out, towards the surface, or into the substrate.

The resistance to these two forces is proportional to the viscosity of the solution. Raising viscosity or decreasing water content will have a negative effect on the absorptive and evaporative forces. The problem then boils down to balancing the absorptive, evaporative, and resistive forces. There are several ways to manipulate them. For example, a less absorbant sheet can be used or surface sizing at the size press lowering the absorb-tive force. The resistance can be raised by the addition of viscosity boosters to the coating mix or raising the solids level of the mix. Also, the evaporative force can be increased through the use of higher temperatures or a radiant type of heat such as an infrared heater.

FIGURE 1



Lowering water raises RESISTANCE, R

○ = pigment particles

°°° = Adhesive particles

⁘ = WATER particles

BINDER MIGRATION $\propto \frac{F_1 F_2}{R}$

ANALYSIS

Looking at the data, these trends appear. The infrared zone has binder almost completely uniformly distributed from the surface down to fourteen ten-thousanths of an inch. Only 2.6% difference shows up from the top and bottom values with the largest difference occuring between the surface (10/10,000) and eight ten-thousanths inches down. Moving to the zone one section, the binder is slightly less uniformly distributed. These is more concentration at the surface and top layers and less at the bottom layers. In zone three the trend is even more pronounced, having the highest percentage of any zone at it's surface and the lowest value encountered in coat one appearing also in zone three at the twelve ten-thousanths level. A graph of the data shows these trends very clearly. The data also shows coat two with the exact same trends with only a slight damping factor, i.e., the migration in either direction is slowed by the addition of alginate. Following is an attempt to explain these phenomena as clearly as possible, using coat one data predominately.

Our coating, upon being applied to the sheet, soaked in immediately because of the absorbance of the sheet. When dried by the infrared section the binder had not yet had too much time but already was fairly well absorbed.

COAT I

	IR	%	Z1	%	Z2	%	Z3	%
0000	.232	17.6	.255	19.6	.234	18.0	.288	22.0
0002	.159	12.2	.209	16.1	.180	13.8	.152	11.7
0004	.172	13.2	.143	11.0	.135	10.4	.126	9.7
0006	.174	13.4	.125	9.6	.143	11.0	.099	7.6
0008	.150	11.5	.147	11.3	.118	9.1	.102	7.8
0010	.198	15.2	.115	9.9	.086	6.6	.098	7.5
0012	.187	14.3	.113	9.7	.097	7.5	.068	5.2
0014	.195	15.0	.118	9.1	.101	7.6	.070	5.4
0016	--	--	.171	13.2	--	--	--	--
blank	.048	3.4						

total cal. 3.5 mils sheet cal. 3.0 mils

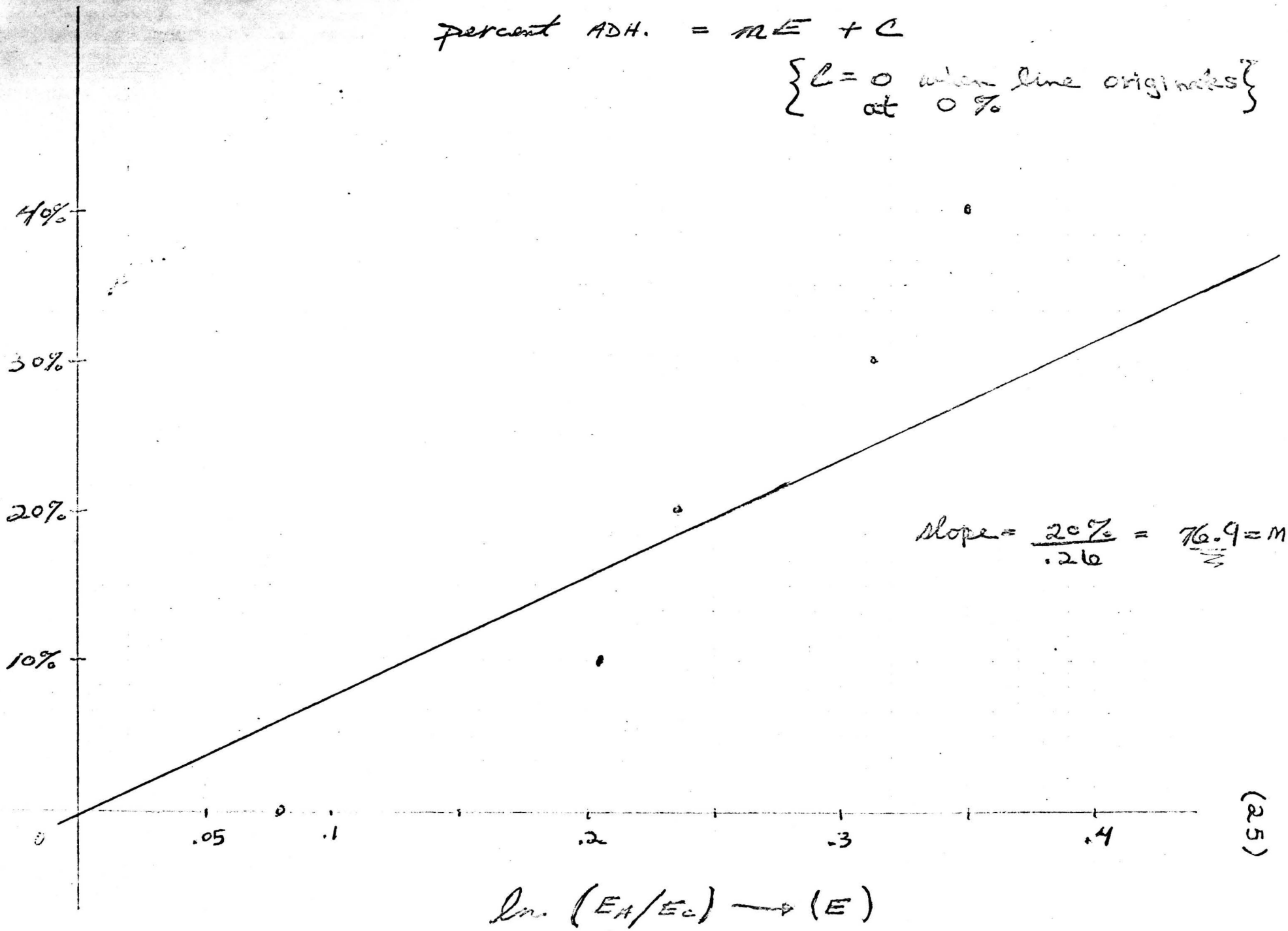
CALIBRATION DATA

0%	.079
10%	.205
20%	.234
30%	.313
40%	.350

M = 76.9

percent ADH. $= mE + C$

$\{C = 0$ when line originates at $0\%\}$



COAT 2

	IR	%	Z1	%	Z2	%	Z3	%
0000	.427	16.0	.442	16.6	.434	16.3	.493	18.5
0002	.327	12.3	.413	15.5	.400	15.0	.307	11.5
0004	.302	11.3	.398	14.9	.356	13.4	.249	9.3
0006	.239	9.0	.351	13.2	.311	11.7	.229	8.6
0008	.189	7.1	.213	8.0	.201	7.5	.159	6.0
0010	.182	6.8	.218	8.2	.190	7.1	.150	5.6
0012	.235	8.8	.168	6.3	.140	5.0	.134	5.0
0014	.213	8.0	.175	6.6	.121	4.5	.117	4.4
0016	.184	6.9	.153	5.7	.101	3.8	.091	3.4
blank	.048							

total caliper (sheet, coating) 3.5 mils

sheet caliper 3.0 mils

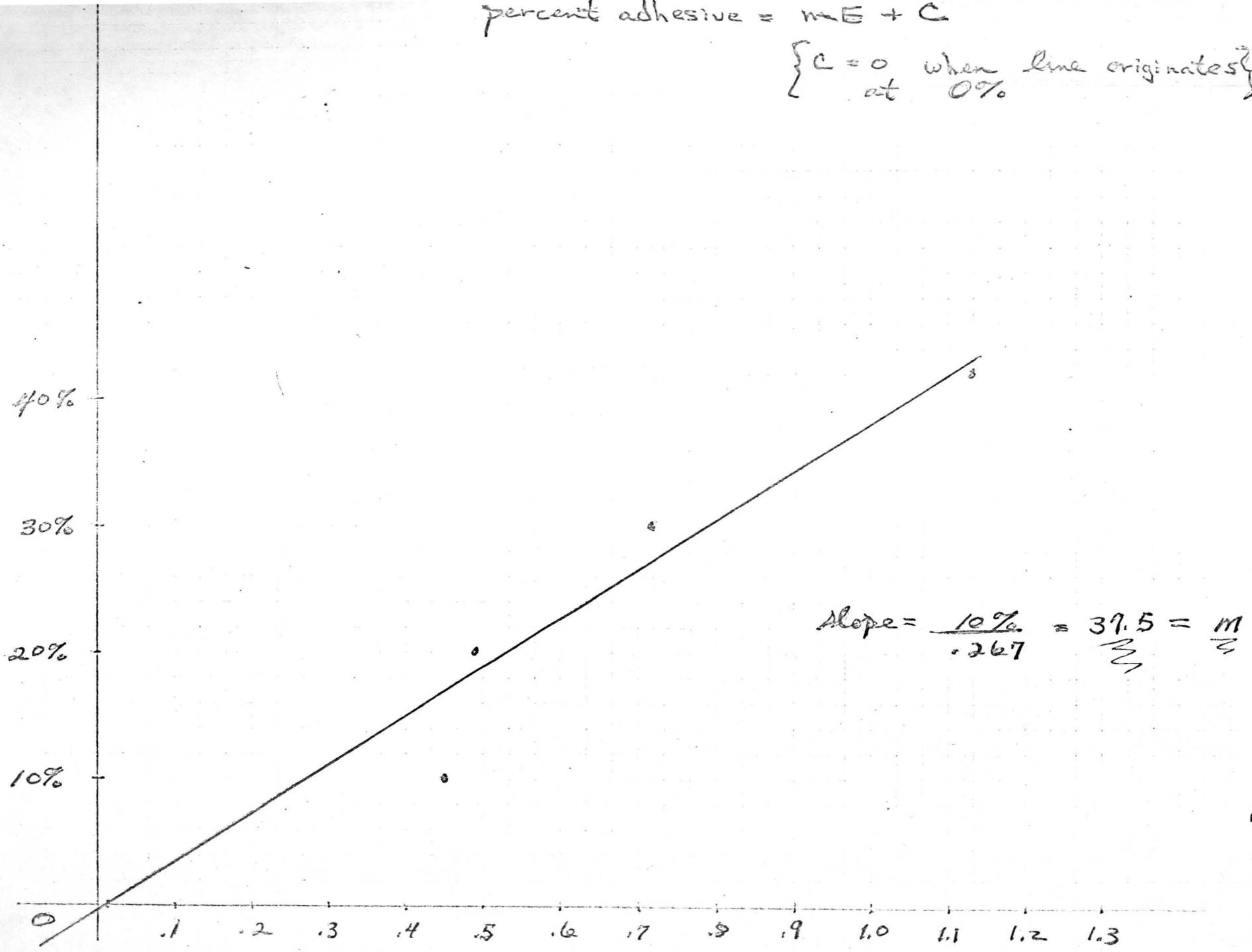
CALIBRATION

0%	.017
10%	.441
20%	.484
30%	.716
40%	1.13

M = 37.5

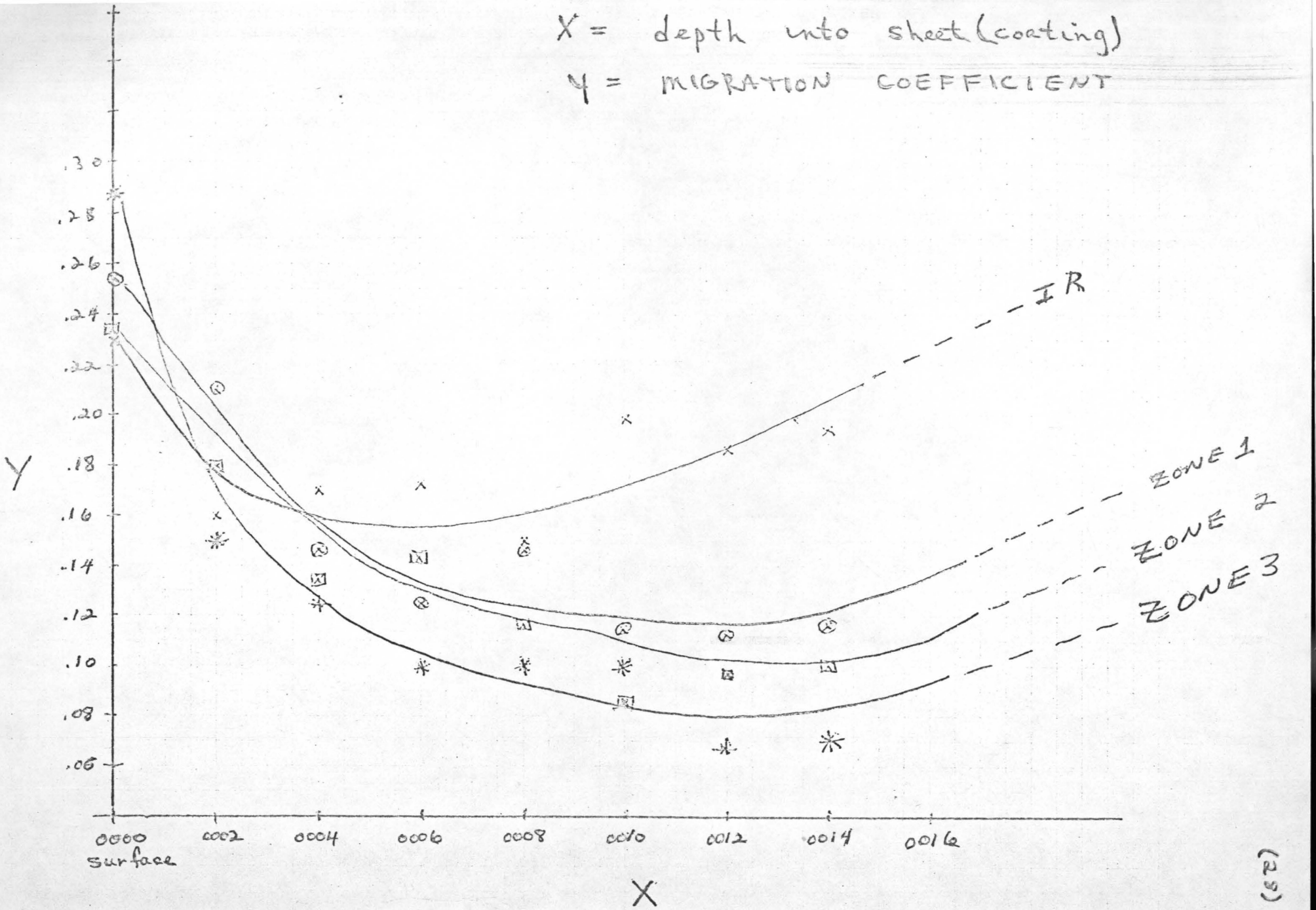
percent adhesive = $mE + C$

{C = 0 when line originates at 0%}



$\text{Slope} = \frac{10\%}{.267} = 37.5 = m$

(27)


X = depth into sheet (coating)
Y = MIGRATION COEFFICIENT
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
Y
IR
ZONE 1
ZONE 2
ZONE 3
0000
surface
0002
0004
0006
0008
0010
0012
0014
0016
X

(52)

When the radiant heat from the infrared heater struck the sheet, water was driven off very fast for a very short time. With a sheet of metal placed on the opposite side of the sheet at the IR heater some heat was reflected back into the sheetfrom the bottom. This helped pull binder toward the bottom offsetting the upward evaporation force caused by the heater directly. What this leaves us is a total of three forces acting on the system, two evaporation forces and one absorbance force. It is suggested that the absorbance force and the downward evaporation force are what offset the upward evaporation force enough to cause the uniformity seen in the IR data.

Moving on to zone one we find more migration to the surface probably because of the lack of a downward evaporation force. We still have an absorbance force, which tends to hold the bottom layers more intact than the top layers upon drying. From this data, as shown on the graph, a tendancy for the binder level to increase occurs at the bottommost levels tested. It would be interesting to measure binder content from the reverse side of the sheet several layers in.

In zone two we encounter even more migration to the surface. The reason postulated for this is as follows. We would expect absorbance to take place until the coating is sufficiently dry, which would lead to more binder concentration in the bottom layers than indicated by the data. However, when the sheet went through zone one, which was at 200° F, evaporation occured, driving binder to the surface.

While the 200° F temperature was not maximum drying temperature, it was plenty warm to cause the water to rise and push binder toward the surface.

Since one zone is a fairly long distance for the sheet to travel (25-30 feet), much longer than the infrared section, a larger time span is available for binder redistribution, in this case, to the surface. The evaporation in the 200° F zones causes what has been termed "thermal migration".(8) Thermal migration occurs because of the water being driven off. However, sufficient water remains to allow subsequent migration to occur before the coating is too dry. Apparently, binder particles require more time to migrate than water molecules, although following the same path.

In zone three we see a continuation of thermal migration has taken place, causing the high concentration of binder at the surface. Thermal migration apparently removed binder from all layers throughout the sheet as water was driven out causing a very sharp drop from the surface to one layer down. The drop is from 22.0% to 11.7% in coat one and 18.5% to 11.5% in coat two, another indication of the damping factor alginate had on binder migration. Zone three binder concentrations show that if more time is allowed more binder will be able to migrate toward the surface during the thermal migration zones.

In conclusion, it would be mentioned that the Perkin Elmer Spectrophometer with MIR attachment was quite satisfactory in that results were quite readily obtained and, once

a technique was extablished, quite reproducible. It seems now that experimenters will have a definite means for measuring binder migration. However, as mentioned earlier, a satisfactory grinding technique is a necessary prerequisite to reliable migration data.

There is something good to be said about infrared drying. The sheet and coating can be dried much faster and, as indicated in our results, yeilds very desirable migration characteristics. However, the key seems to be to work in a combination of infrared drying with some other conventional means of drying, the proper amount of each depending on the specific paper coating system.

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Appendix

THE EFFECT OF DRYING RATES ON BINDER MIGRATION

Experimental Plan

Performed by: Alan Larson and Pete Bradshow in the Fall of 1974 and Winter of 1975 semesters at Western Michigan University in fulfillment of course number 470 of the Paper Engineering curriculum.

Advisor: James Kline

Objective: To determine effective drying rate of a particular paper-pigment-adhesive system, by moving the hot zone forward in the drying sequence.

COAT # 1

PIG.	Latex # 1	H_2O	AIG.
33.4% 30 lbs (dry)	16.6% 5.0 lbs (dry)	50% 35 lbs	0 -

COAT # 2

PIG.	Latex # 1	H_2O	AIG.
33.4% 30 lbs (dry)	16.6% 5.0 lbs (dry)	50% 35 lbs	2% .12 lbs

COAT # 3

PIG.	Latex # 2*	H_2O	AIG.
33.4% 30 lbs	16.6% 5.0 lbs	50% 35 lbs	0% -

COAT # 4

PIG.	Latex # 2	H_2O	AIG.
33.4% 30 lbs	16.6% 5.0 lbs	50% 35 lbs	2% .12 lbs

COAT # 5

PIG.	Latex #2	H_2O	AIG.
33.4%	16.6%	50%	-
30 lbs	5.0%	35%	-

(Run on seperate base sheet, specially impregnated with latex)

COATER DRYER HOT ZONES

There are four zones; by making one zone much hotter and then moving hot zone forward, drying rate is changed.

	1(IR)	2	3	4
1st zone	OFF	200	200	350
2nd zone	OFF	200	350	200
3rd zone	OFF	325	200	200
4th zone	ON 1000,000 BTU	200	200	200

Hot IR zone= fastest drying rate.

MATERIALS

PIGMENT- 5 coatings
4 drying rates

at 30 sec./rate and 5 minute stabilize time = 7 minutes
(12lb/ream) (250 fpm x 2ft wide/3300) (2 lb/min) (7min)
= 14 lbs dry.

double each figure for insurance
take 30 lbs dry clay #2 for each coating

total: 30 x 5 = 150 lbs. dry pigment

LATEX- 5 coatings
4 drying rates
@ 16.6% on dry pigment.

total: 150 x .166 = 25.0 lbs. dry latex

$\frac{25}{5}$ = 5.0 lbs. dry latex per coating

Alginate- supplied and calculated by partner, Pete Dardshaw in conjunction with his own thesis on the effect of alginates on binder migration.

Substrate- highly absorbant, minimum sizing.

@ 250 fpm, 5 coatins @ 15 minutes each= 18,580 ft x 2ft width= 37,160 ft^2

(length x width/3,300 ft^2/ream)

37,160 ft^2/3300 ft^2/ream
Total= 11.2 reams (max.)

B.W. - 42#/ream (3300) = 470# total

H_2O- add as needed to raise coating to 50% solids.

MACHINE SPECIFICS

Air Knife

speed: 250 feet/minute
air: 1.25#air
BW: 42#/3300 ft^2
Coat Wt.: 12 lbs/3300 ft^2

1 IR dryer, 3 AIR Hood Dryers

(Hang IR dryer some date prior to day of run.)

REMARKS

ORIGIN _____

PURITY _____

PHASE _____

CONCENTRATION _____

THICKNESS _____

DATE _____

OPERATOR _____

PERKIN-ELMER
MODEL 700

SPECTRUM NO. _____

SAMPLE 1 _____

SAMPLE 2 _____

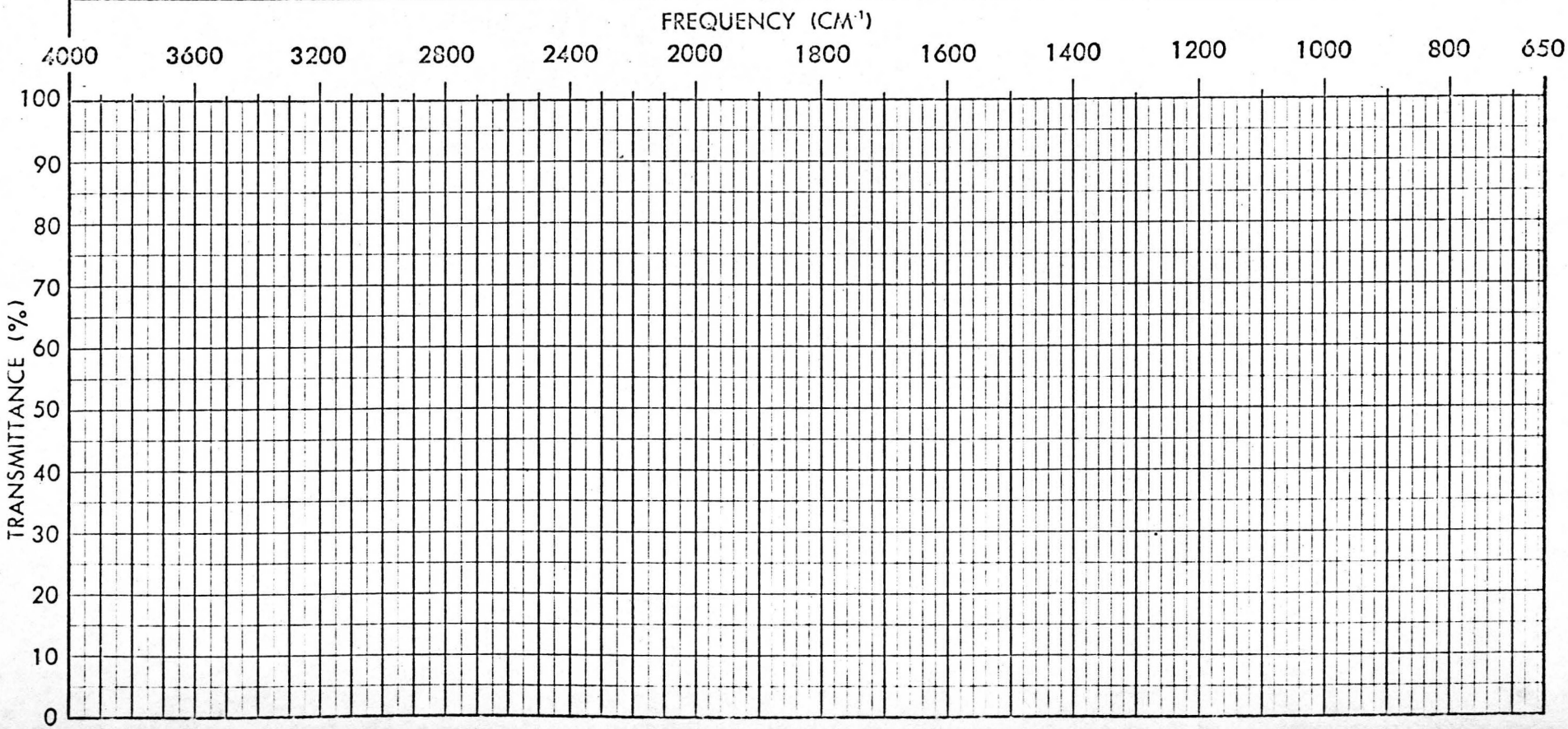


FIGURE 2

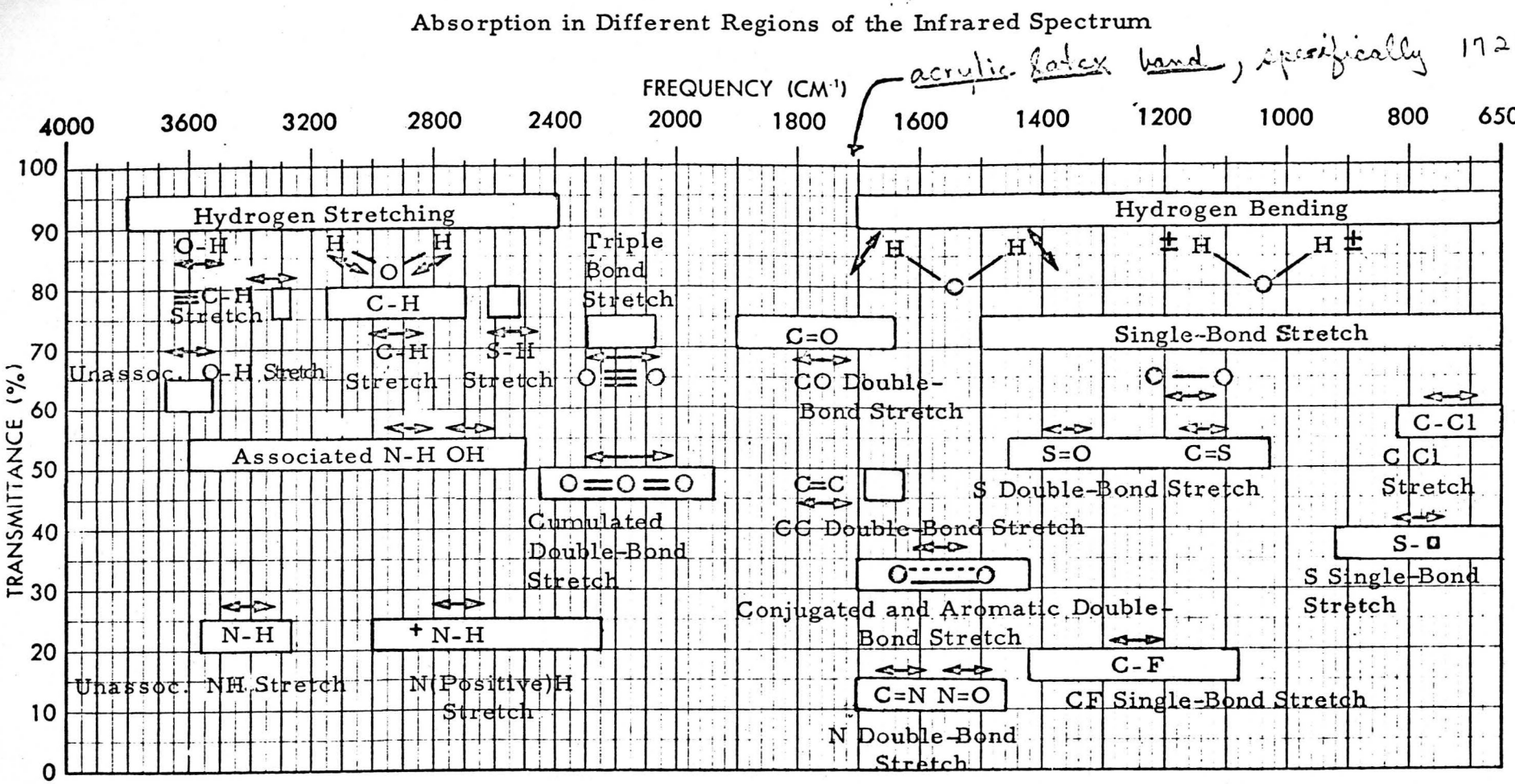

Absorption in Different Regions of the Infrared Spectrum
acrylic latex band, specifically 1725 cm-1
FREQUENCY (CM-1)
4000
3600
3200
2800
2400
2000
1800
1600
1400
1200
1000
800
650
TRANSMITTANCE (%)
100
90
80
70
60
50
40
30
20
10
0
Hydrogen Stretching
O-H
Unassoc. O-H Stretch
≡C-H Stretch
C-H Stretch
C-H Stretch
S-H Stretch
Associated N-H OH
N-H
Unassoc. NH Stretch
+ N-H
N(Positive)H Stretch
Triple Bond Stretch
O=O=O
Cumulated Double-Bond Stretch
Hydrogen Bending
C=O
CO Double-Bond Stretch
C=C
CC Double-Bond Stretch
Conjugated and Aromatic Double-Bond Stretch
C=N N=O
N Double-Bond Stretch
Single-Bond Stretch
S=O
C=S
S Double-Bond Stretch
C-F
CF Single-Bond Stretch
C-Cl
C Cl Stretch
S-
S Single-Bond Stretch

FIGURE 3

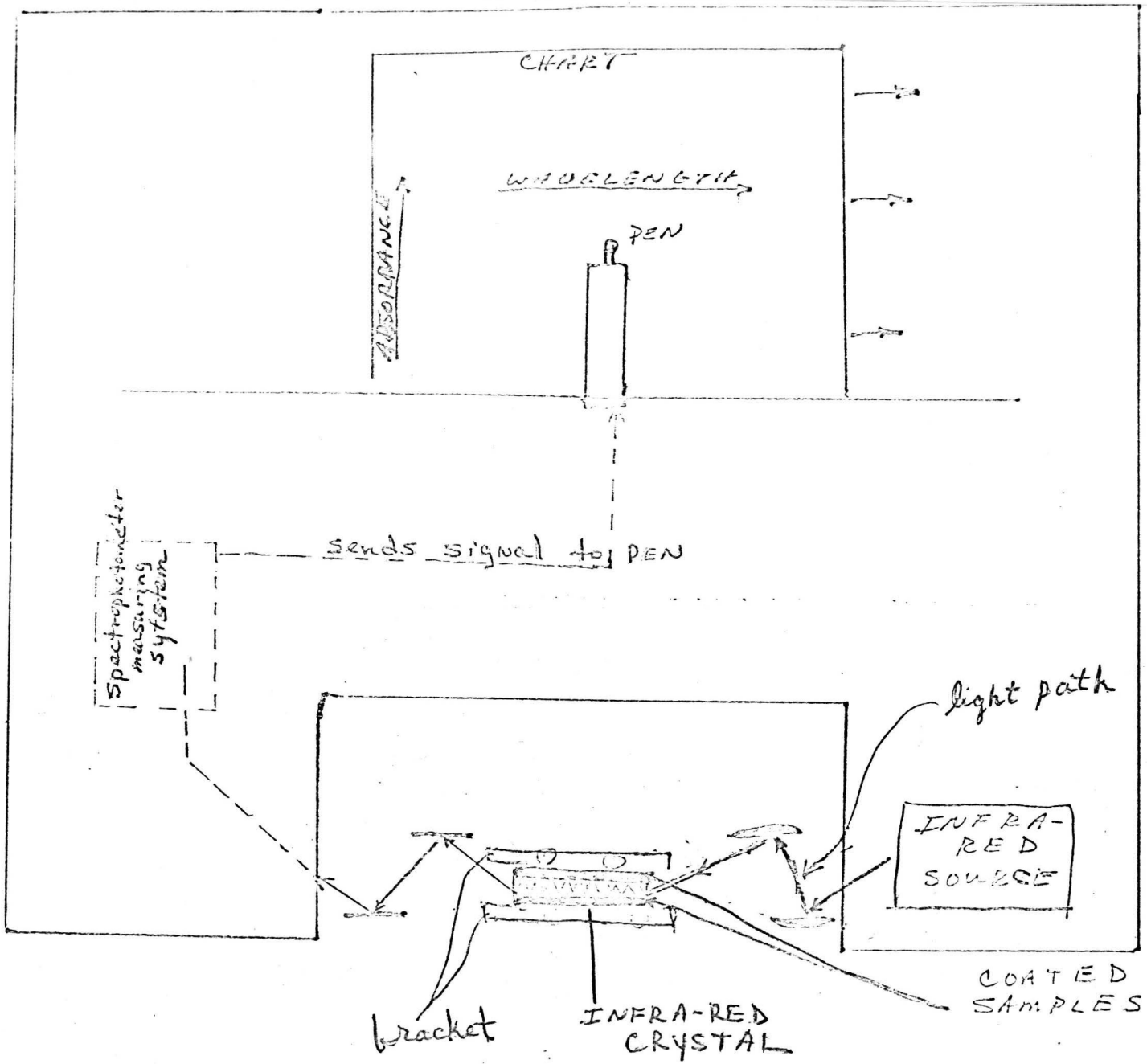
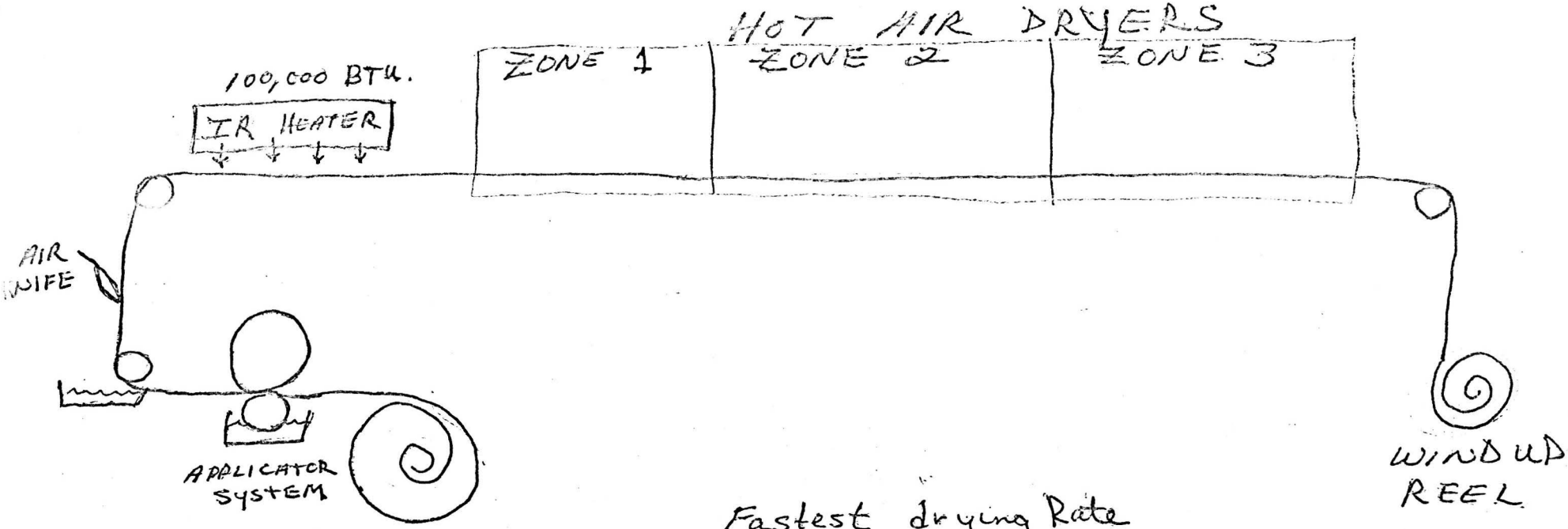


FIGURE 4
MIR unit



Fastest drying Rate
is with IR dryer on

FIGURE 5
COATING MACHINE